… for a brighter future

Evaluating The Optimal Strategy For Dark Energy Survey Supernovae

Joseph P. Bernstein

High Energy Physics Division
Argonne National Lab, U.S.A.

Richard Kessler (U. Chicago, U.S.A.)
Stephen Kuhlmann (Argonne, U.S.A)
Harold Spinka (Argonne, U.S.A.)
for the Dark Energy Survey Collaboration

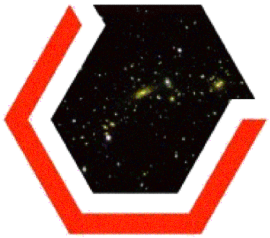
Postdoctoral Research Symposium, Argonne, IL, Sept. 11, 2008

UChicago ▶
Argonne LLC

A U.S. Department of Energy laboratory
managed by UChicago Argonne, LLC

Outline

- Introduction to cosmology
- Dark energy survey supernovae
- Light curve simulator & fitter
- Bias studies
- Survey figure of merit
- Summary & conclusions



DARK ENERGY SURVEY

Argonne NATIONAL LABORATORY

Office of Science
U.S. Department of Energy

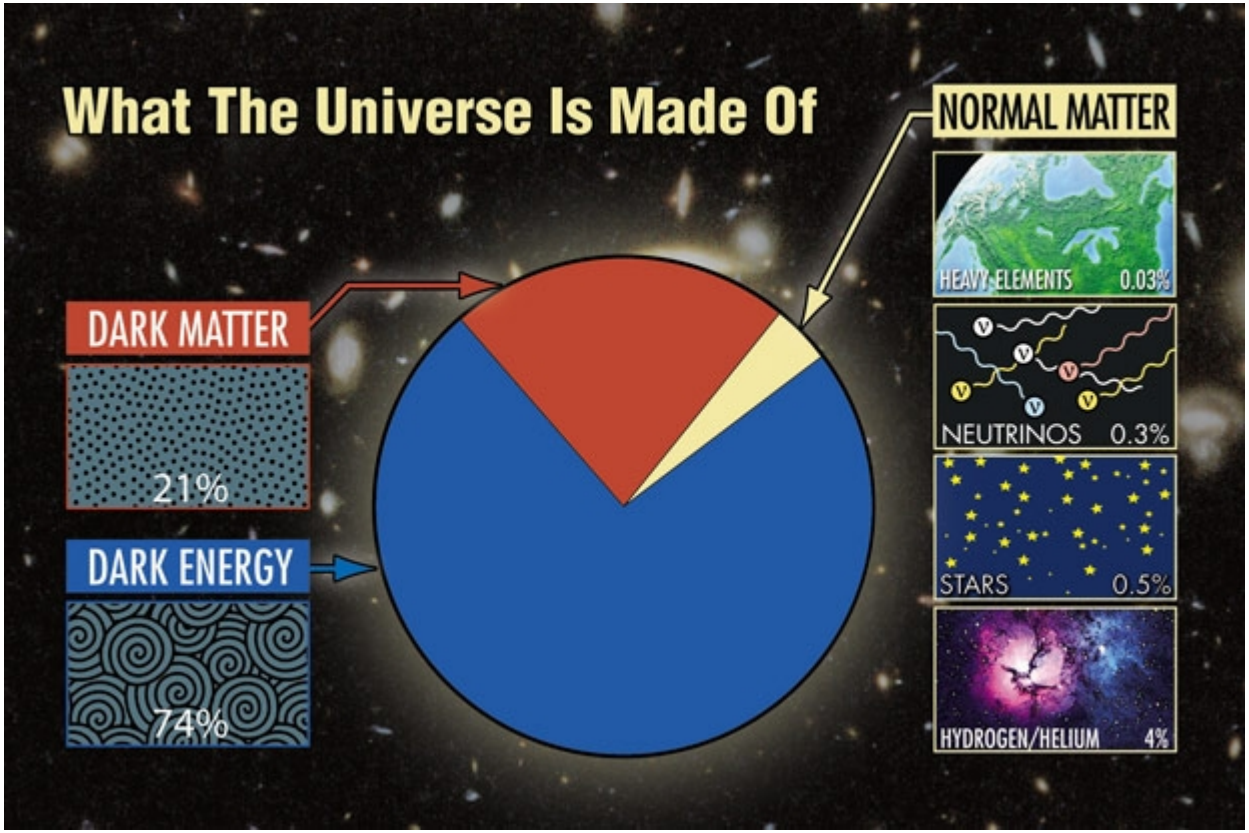
University of Chicago

Fundamental Motivation

DARK ENERGY SURVEY

Discovering the evolution & ultimate fate of the Universe and determining what constitutes 95% of the Universe!

Have A Slice Of Universe Pie



Courtesy: http://hetdex.org

Quantifying Past & Future Evolution

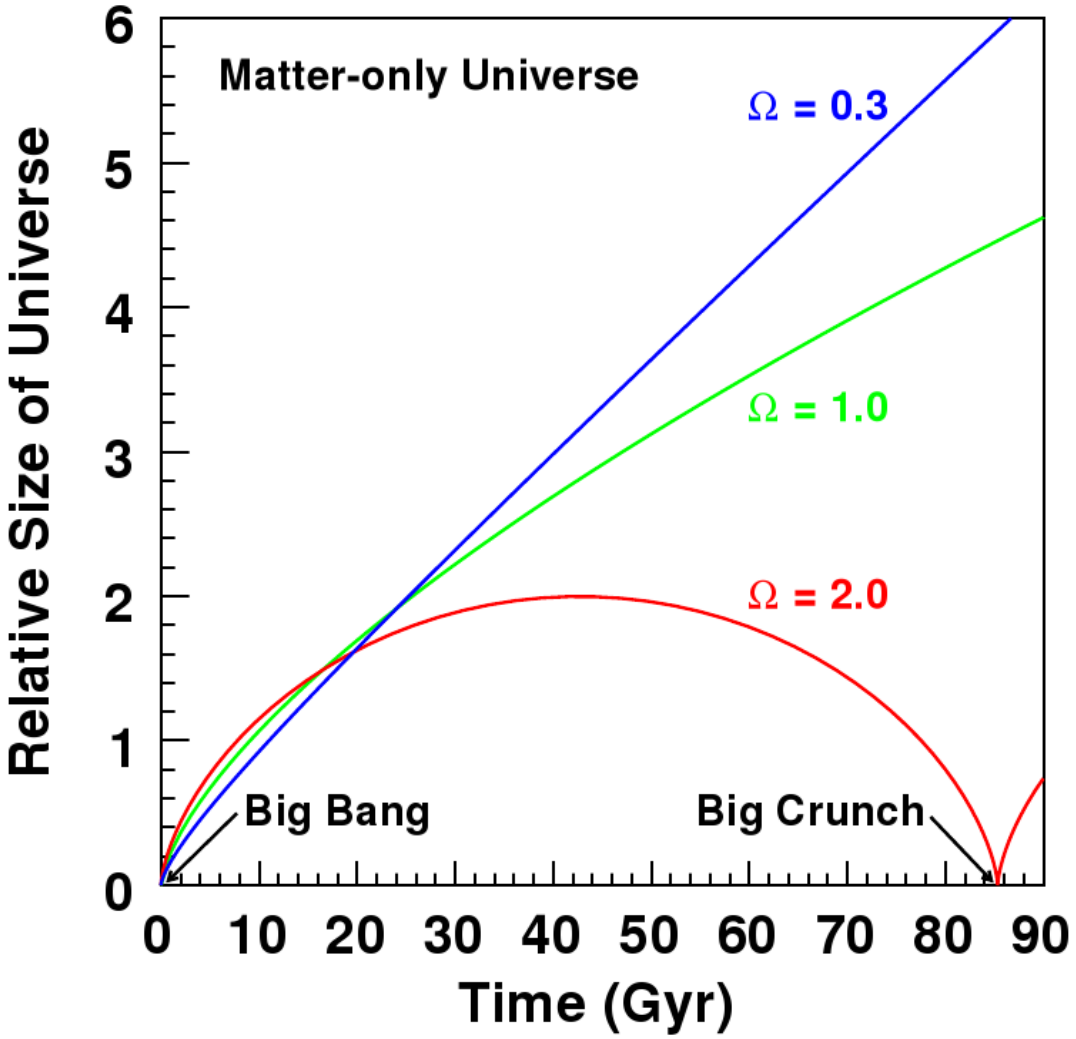
DARK ENERGY SURVEY

Observation:
Universe is expanding!

Evolution depends on energy density ρ

Define: $\Omega \equiv \rho/\rho_{\mathrm{crit}}$

ρ_{crit}: density required for expansion of Universe to halt asymptotically



Quantifying Cosmology

DARK ENERGY SURVEY

Theory motivates & data show that Universe is flat:

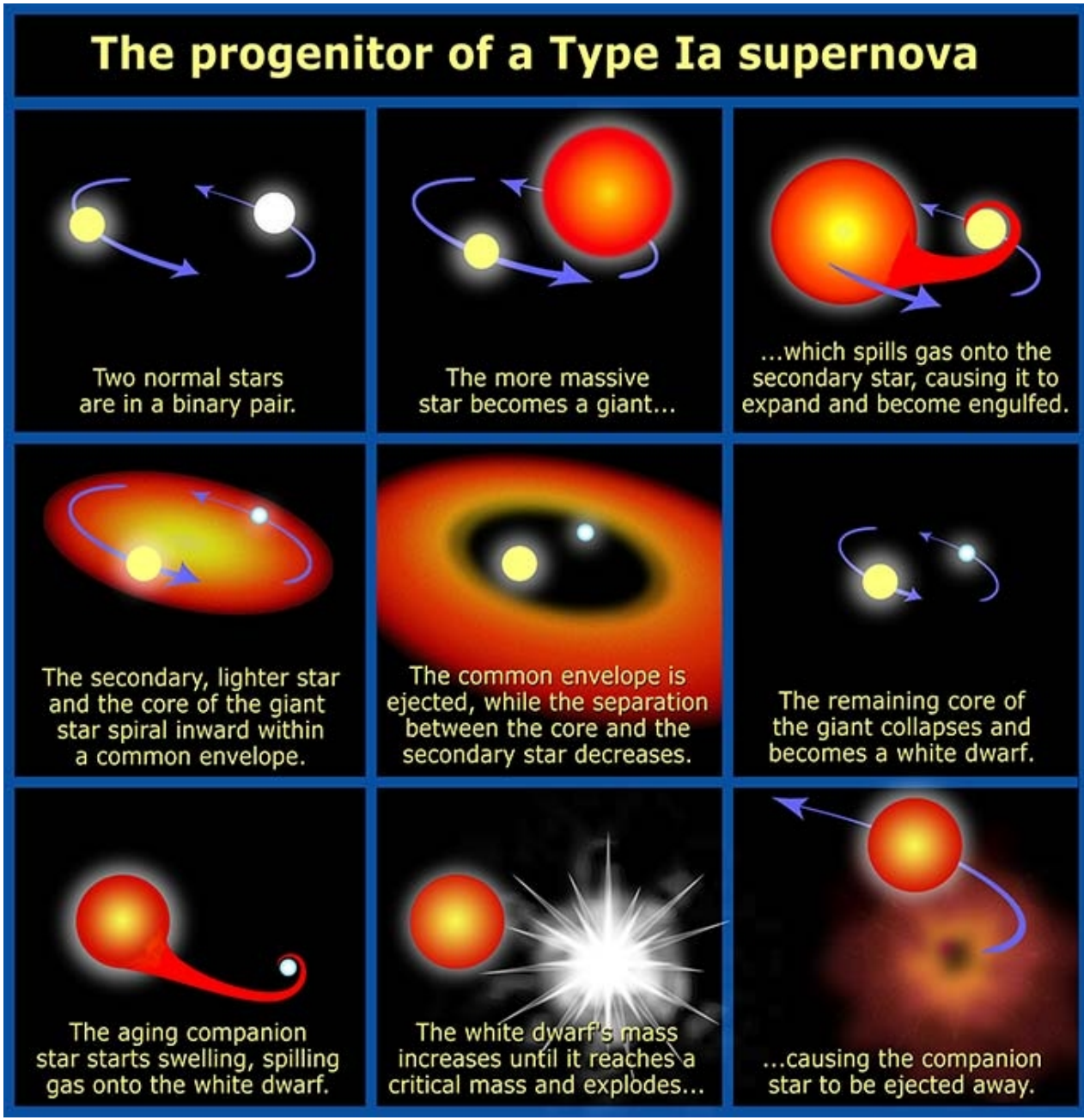
$\Omega_{tot} = 1$

Observations indicate matter comprises only 25%:

$\Omega_{m} = 0.25$

What makes up the other 75%?

Towards An Answer



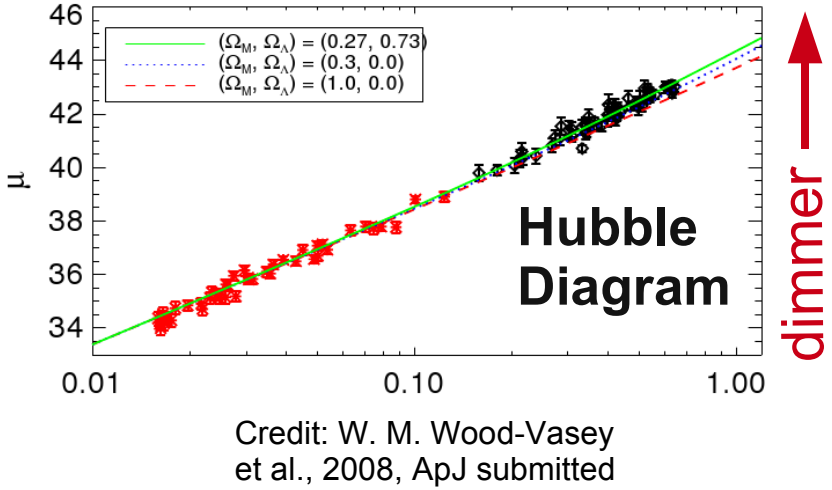
Courtesy:http://hubblesite.org

BRIGHT!

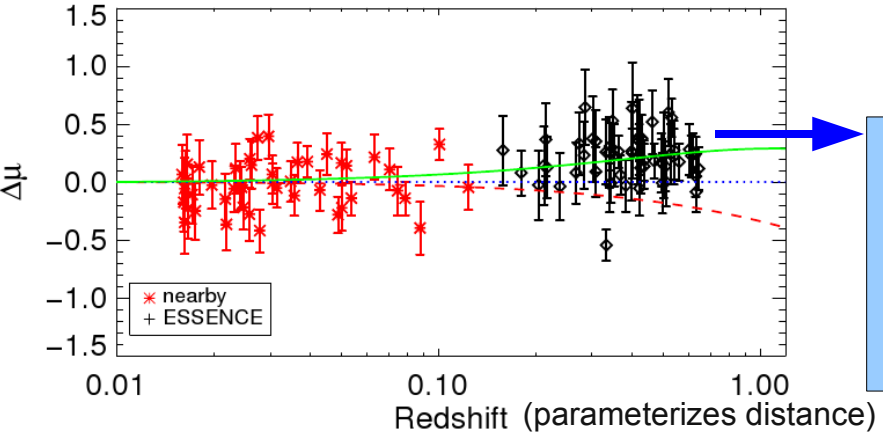
NCG 4526 is ~55 million light years away from Earth ⇒ the light from SN 1994D started traveling towards Earth ~55 million years before 1994!

SNe As Standard Candles

DARK ENERGY SURVEY



Credit: W. M. Wood-Vasey et al., 2008, ApJ submitted



Distance modulus:

$\mu = m - M = 5\log_{10}(d/10\ pc)$

d = distance (1 pc = 3.09×10^{16} m)

m = apparent magnitude of object

M = absolute magnitude of object

$m_1 - m_2 = -2.5\log_{10}[(L_1/L_2)(d_2/d_1)^2]$

L = luminosity (units: energy/sec)

Distant SNe dimmer than predicted for a matter-only Universe! Originally discovered in 1998

Quantitative Framework For Dark Energy

DARK ENERGY SURVEY

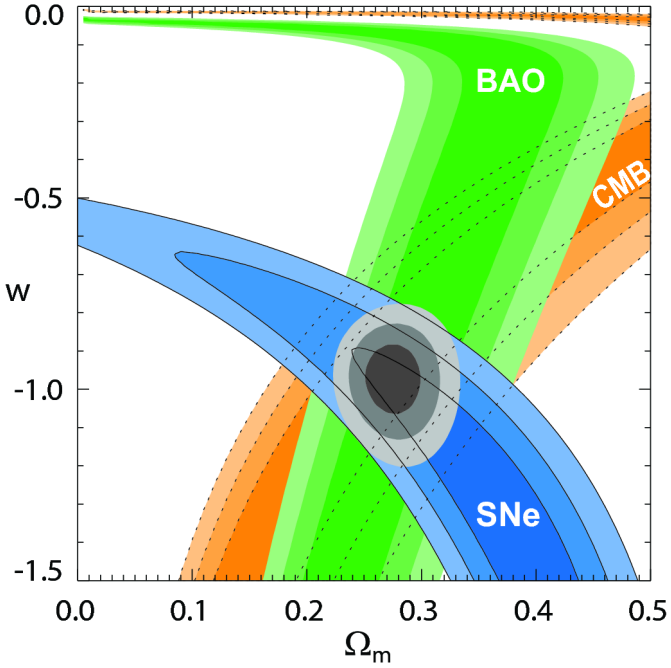
Explanation: expansion of Universe is accelerating due to dark energy that has strongly negative pressure (p_{DE})

Dark energy equation of state: $w = p_{DE}/\rho_{DE}$

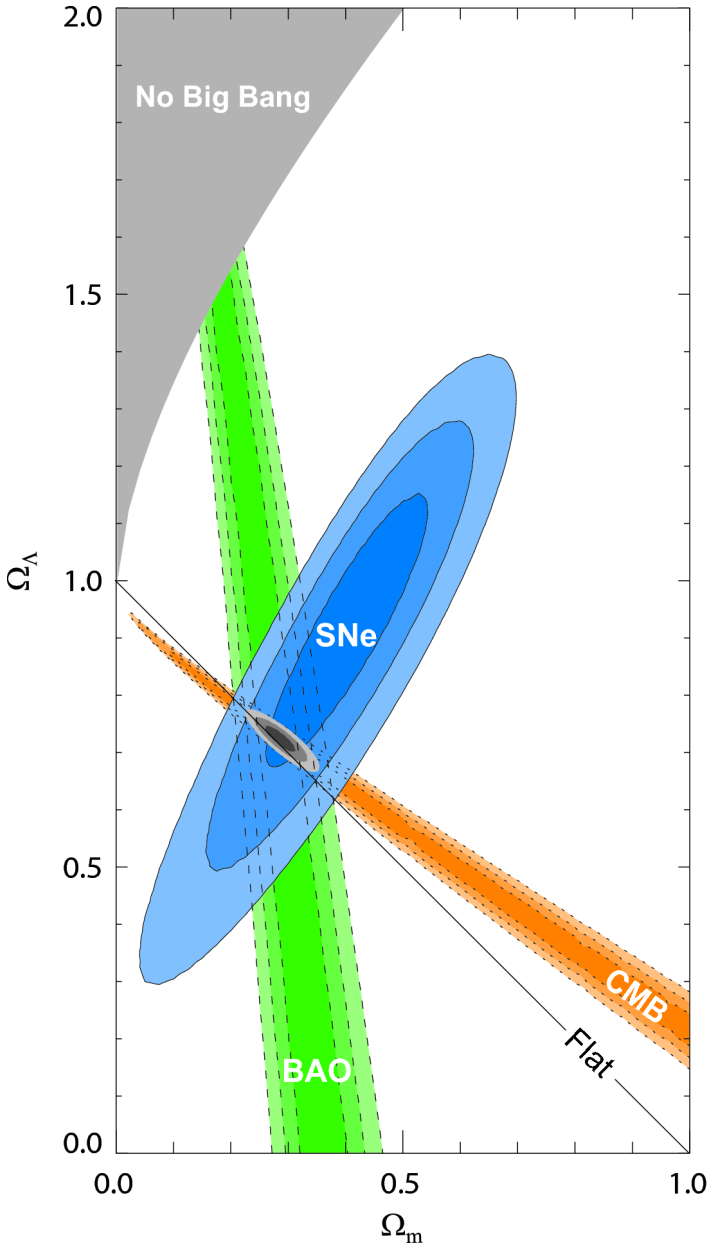
Dark energy density today: $\Omega_{DE} = \rho_{DE}/\rho_{crit}$

Default cosmology: $w = -1$
Einstein's cosmological constant

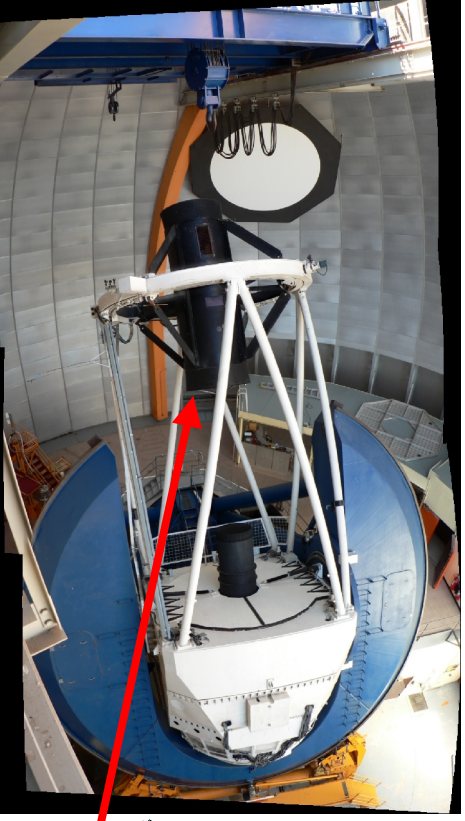
Current Constraints

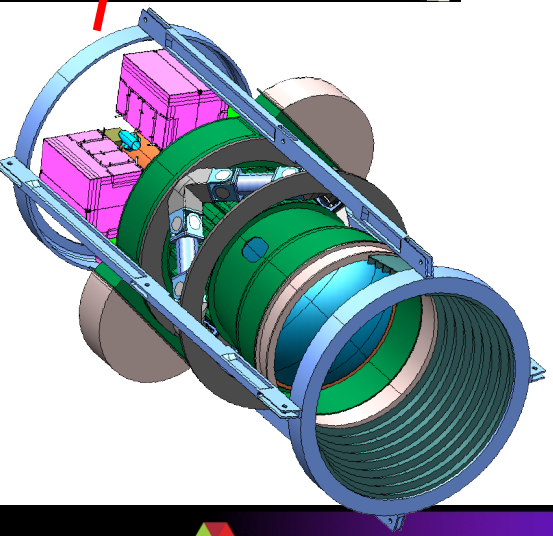


Credit: Kowalski et al. 2008, ApJ, accepted



DARK ENERGY SURVEY





Dark Energy Survey (DES)

DARK ENERGY SURVEY

DES will survey 5000 square degree of sky and provide new 520Mpixel CCD camera (DECAM) for the Blanco 4m telescope in Chile in exchange for 525 survey nights over 5 years starting in 2011

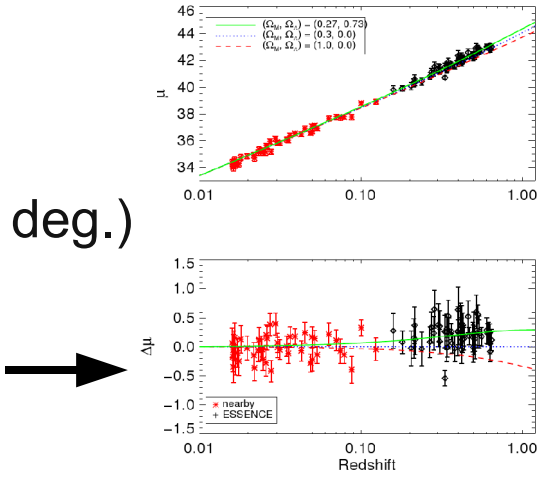
DE investigation via 4 independent probes:
1) Galaxy angular clustering
2) Weak gravitational lensing tomography
3) Baryon acoustic oscillations
4) SN Ia distances

DES is expected to observe ~10^6 galaxies & will obtain redshifts for the South Pole Telescope survey

DES Supernovae

DARK ENERGY SURVEY

- DES time allocation fixes total supernovae (SNe) exposure time
  - 1000 hr planned over 5-year survey period
  - maximal use of non-photometric time (~500 hr) planned
- Time per field & number of fields can be simulation optimized
  - ultra-deep strategy (3 square degrees = 1 DES field)
  - deep strategy (9 square deg.)*
  - shallow but wide strategy (27 square deg.)
  - hybrid strategy, e.g., 3 deep + 2 wide (15 square deg.)
- Need redshift for each SN to make Hubble Diagram



* Highlighted in DES DOE proposal

DES Redshifts And Spectroscopy

DARK ENERGY SURVEY

- Using SNe Ia for cosmology
  - need *redshift* of each SN
  - requires spectrum or detailed colors
  - ⇒ formulate spectroscopic strategy

$$1+z \equiv \lambda_{obs}/\lambda_{emit}$$

$z \equiv$ *redshift*

λ_{obs} = observed wavelength

λ_{emit} = emitted wavelength

NB. distance $\propto$ func(z,Ω)

- Spectroscopy of full SNe sample?
  - redshift error ~0.01
  - expensive (spectroscopic telescope follow-up time)
- Redshift critical for distinguishing type Ia & II SNe
  - spectroscopic follow-up for ~25% of SN sample
  - rest: photometric redshifts in real time (error ~0.02-0.03) & host galaxy follow-up (errors 0.001)

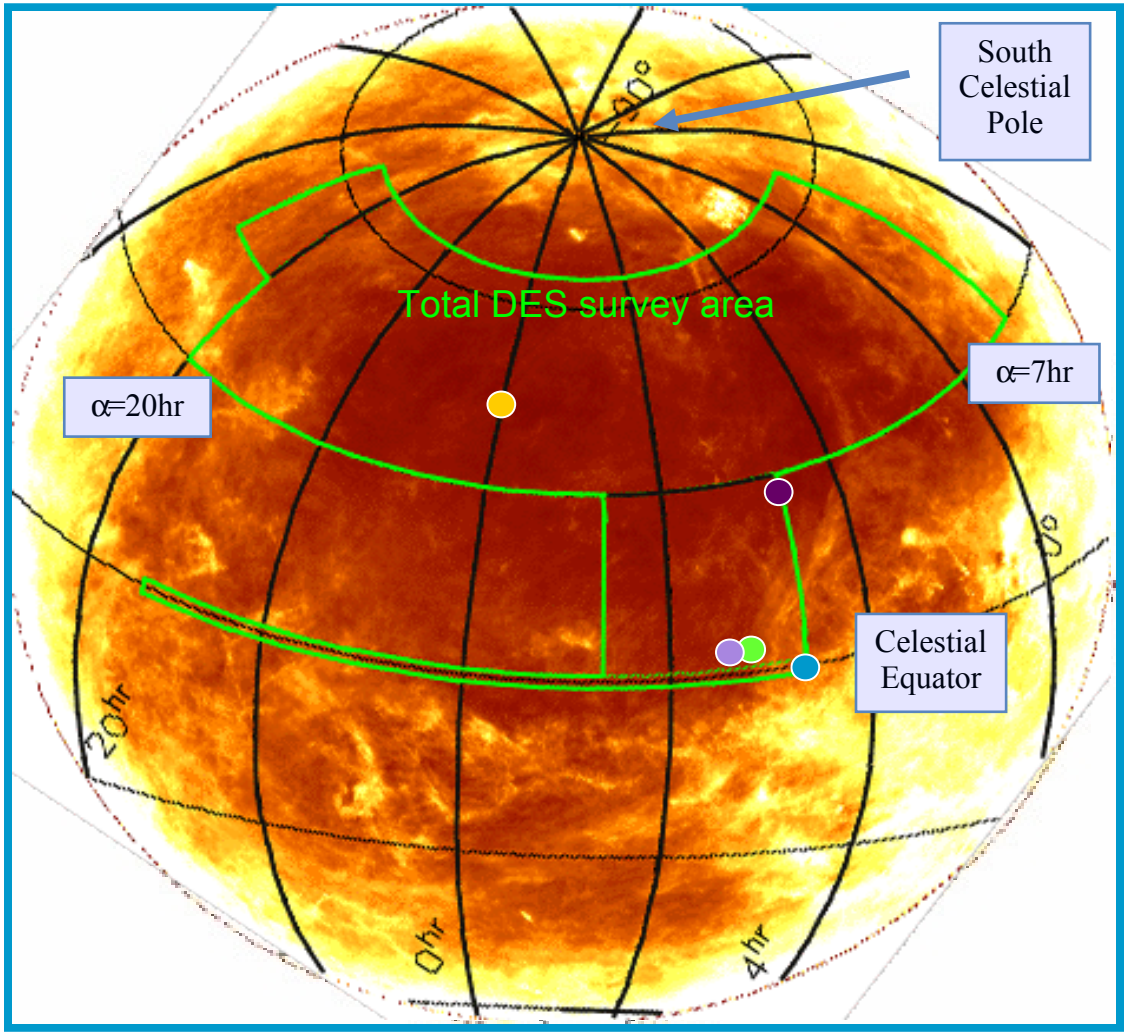
Current Favored DES Supernovae Fields

DARK ENERGY SURVEY

- Chosen to maximize:
  - visibility from DES site
  - past observation history
  - visibility from, e.g, Hawaii

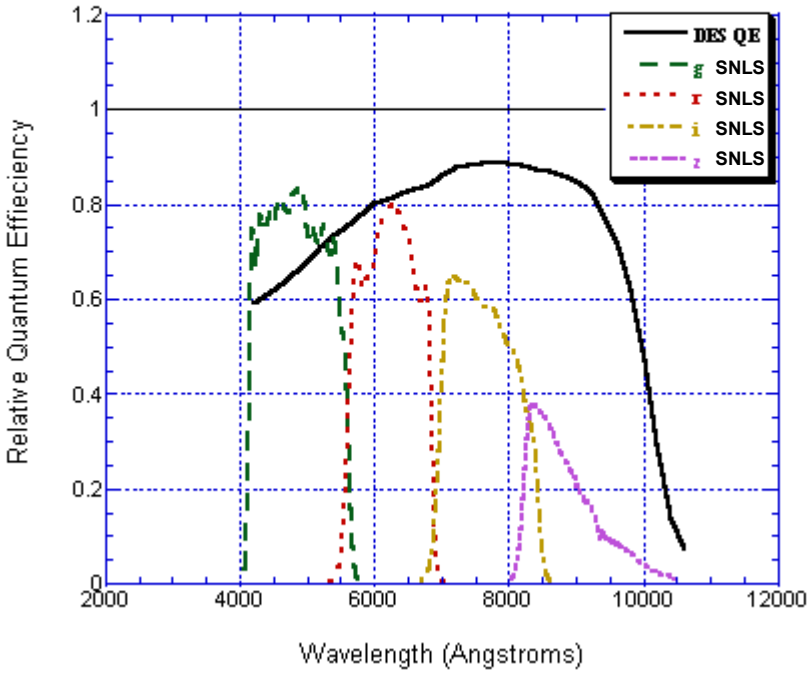
Chandra Deep Field – South
Sloan Stripe 82
SN Legacy Survey (SNLS) D1
XMM-Newton LSS
ELIAS S1

From a study by Peter Nugent



DES vs. Supernova Legacy Survey (SNLS)

DARK ENERGY SURVEY



Courtesy: John Marriner

DES uses thicker LBNL CCDs with increased red sensitivity ⇒ improved z-band performance

DES will also have 5–10 times better statistics

SNANA Software Package Used By DES

DARK ENERGY SURVEY

R. Kessler (U. Chicago), J. P. Bernstein, S. Kuhlmann, & H. Spinka (ANL)

- Software suite for simulating and fitting SN light curves
- Publicly available: http://www.hep.anl.gov/des/snana_package
- Allows an accurate & complete study of DES Supernovae observations including detailed filter characteristics, realistic weather & cadence considerations, dust extinction effects, CCD properties, etc.
- Also used by other projects
  - Sloan Digital Sky Survey (SDSS)
  - Large Synoptic Survey Telescope (LSST) SN project

SNANA SN Light Curve Fitter & Simulator

DARK ENERGY SURVEY

- Computes rest-frame model magnitudes using various models
- Applies random color/luminosity fluctuations
- Includes host galaxy dust extinction
- Applies K-corrections: transforms observed measurements at redshift z, into a standard measurement at redshift zero
- Sets choice of cosmology
- Applies Milky Way dust extinction via Schlegel maps*
- Converts magnitudes to flux
- Adds CCD gain, signal noise, and sky noise

Fitter included for resulting light curves

*Schlegel, Finkbeiner, Davis 1998, ApJ, 500, 525

Multicolor Light Curve Shape Model

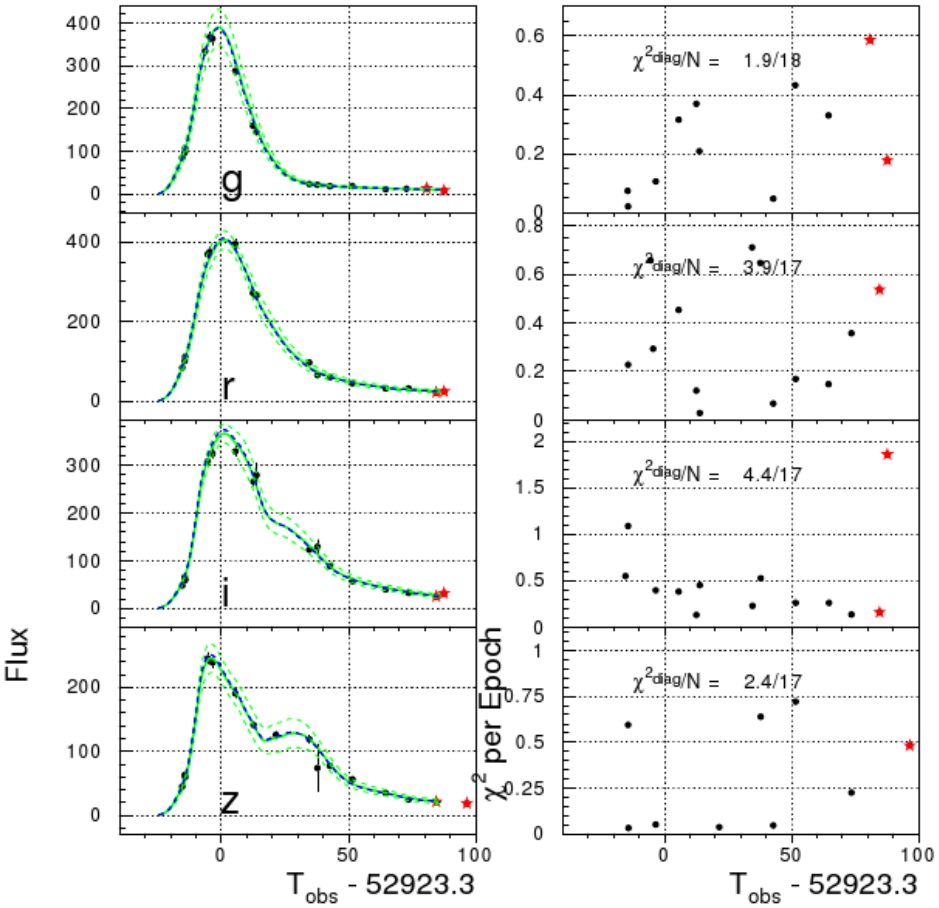
(MLCS2k2; Jha, Riess, Kirshner 2007, ApJ, 659, 122)

DARK ENERGY SURVEY

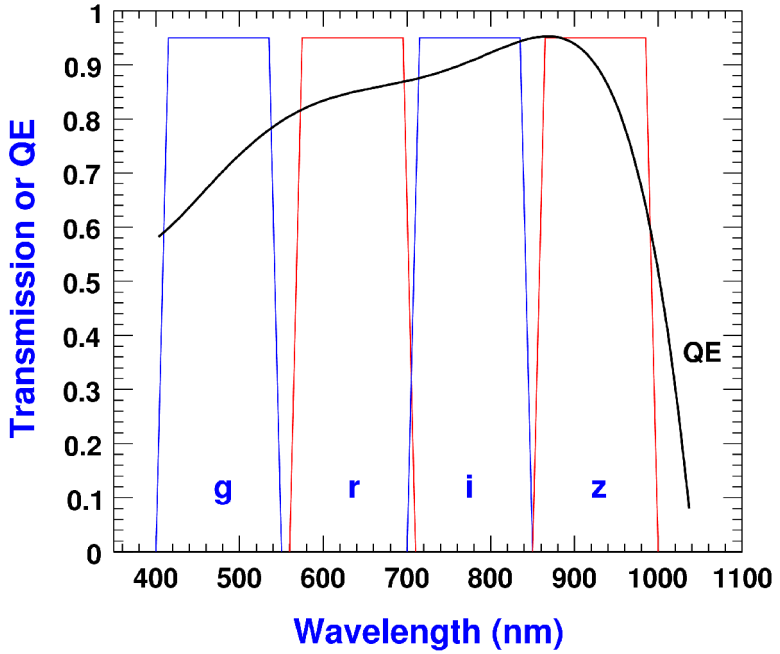
- Light curve model of apparent brightness as function of time
  - templates from observations give shape/brightness relation
  - accounts for dust extinction in Milky Way
- Free parameters
  - epoch of maximum light in B-band
  - distance modulus (μ)
  - luminosity/light curve shape parameter (Δ)
  - amount of extinction in magnitudes* (A_V) by host-galaxy dust

*Cardelli, Clayton, Mathis 1989, ApJ, 345, 245, and references therein

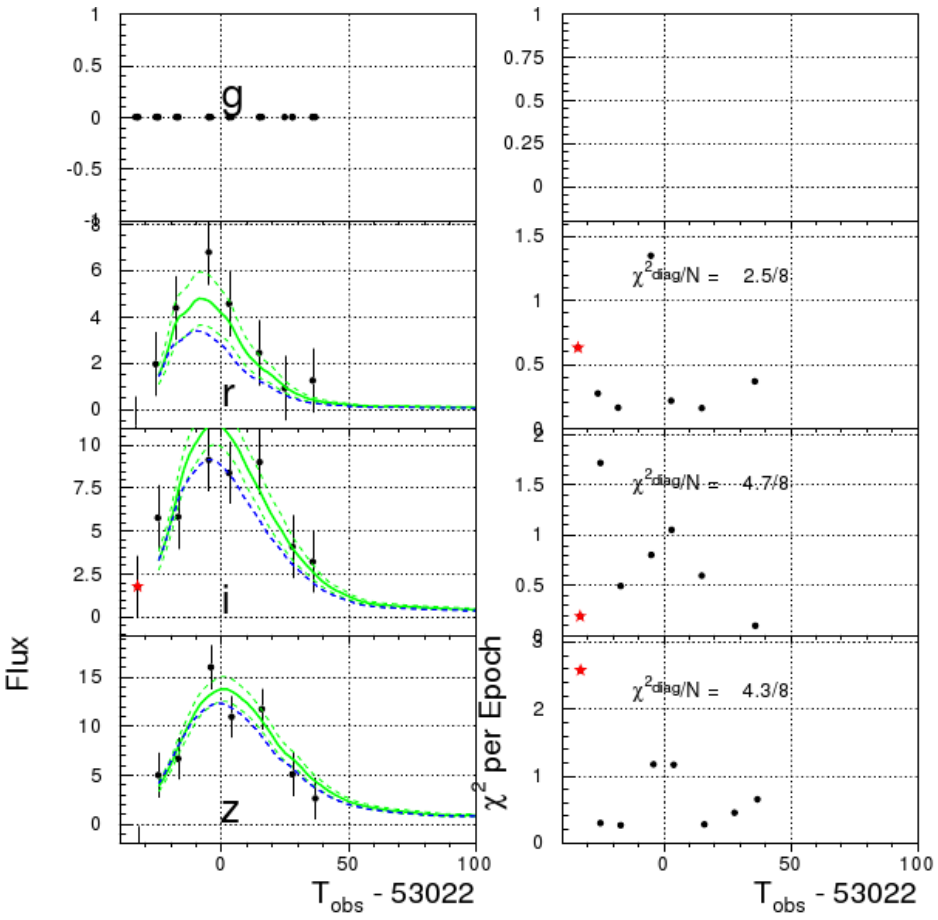
Simulated DES SN Light Curves



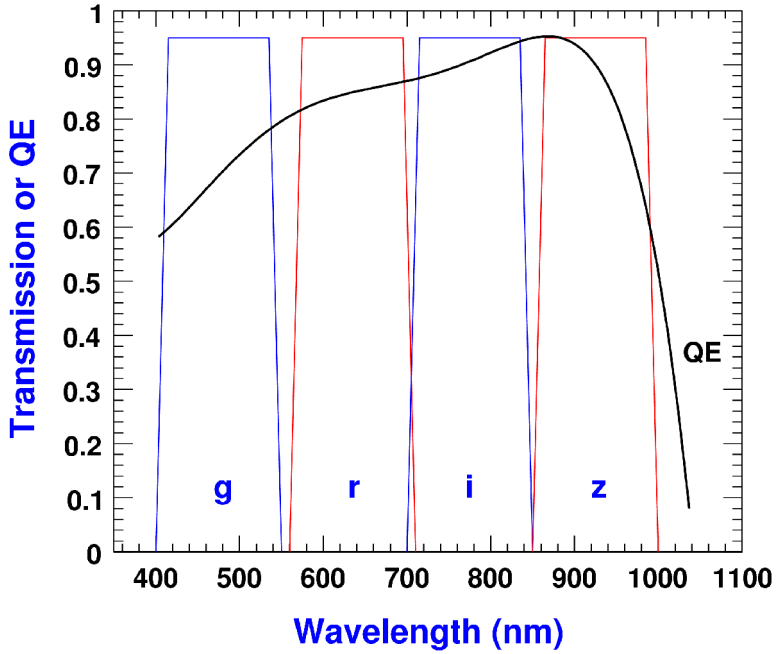
Example light curve at redshift of ~0.24 for a hybrid survey (15 sq. deg.) using the griz filter set – note 2nd bump unique to SNe type Ia



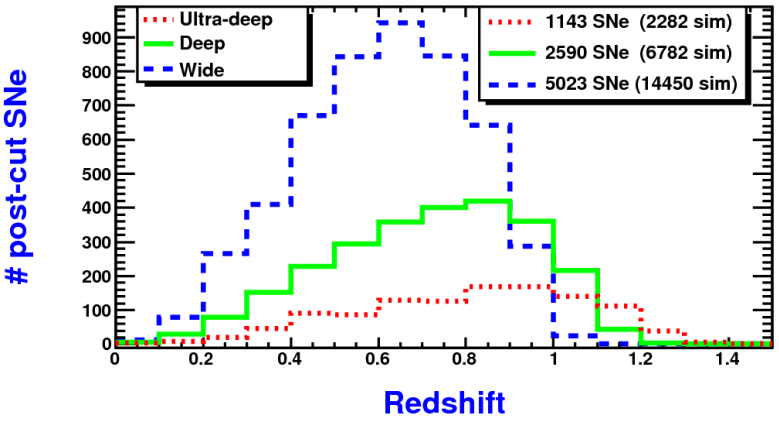
Simulated DES SN Light Curves

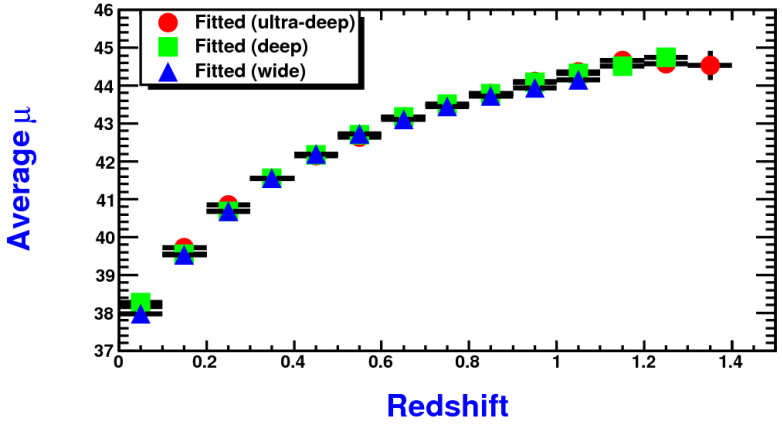


Example light curve at redshift of ~1.09 for a hybrid survey (15 sq. deg.) using the griz filter set – note lack of 2nd bump unique to SNe type Ia, and that g-band is redshifted out of range

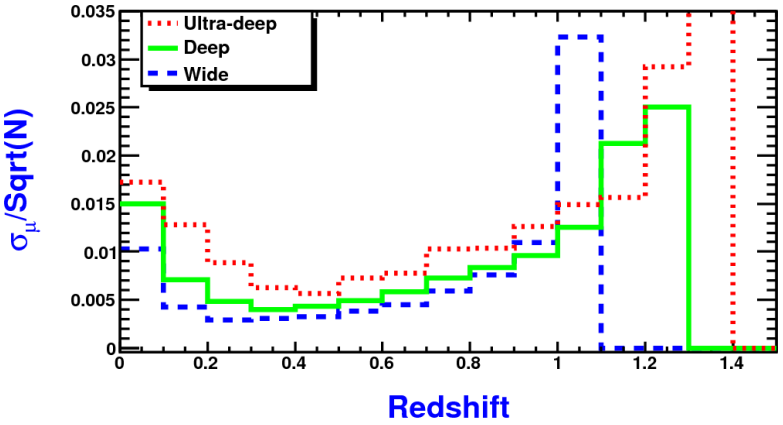


Number Of SNe & Statistical Distance Error

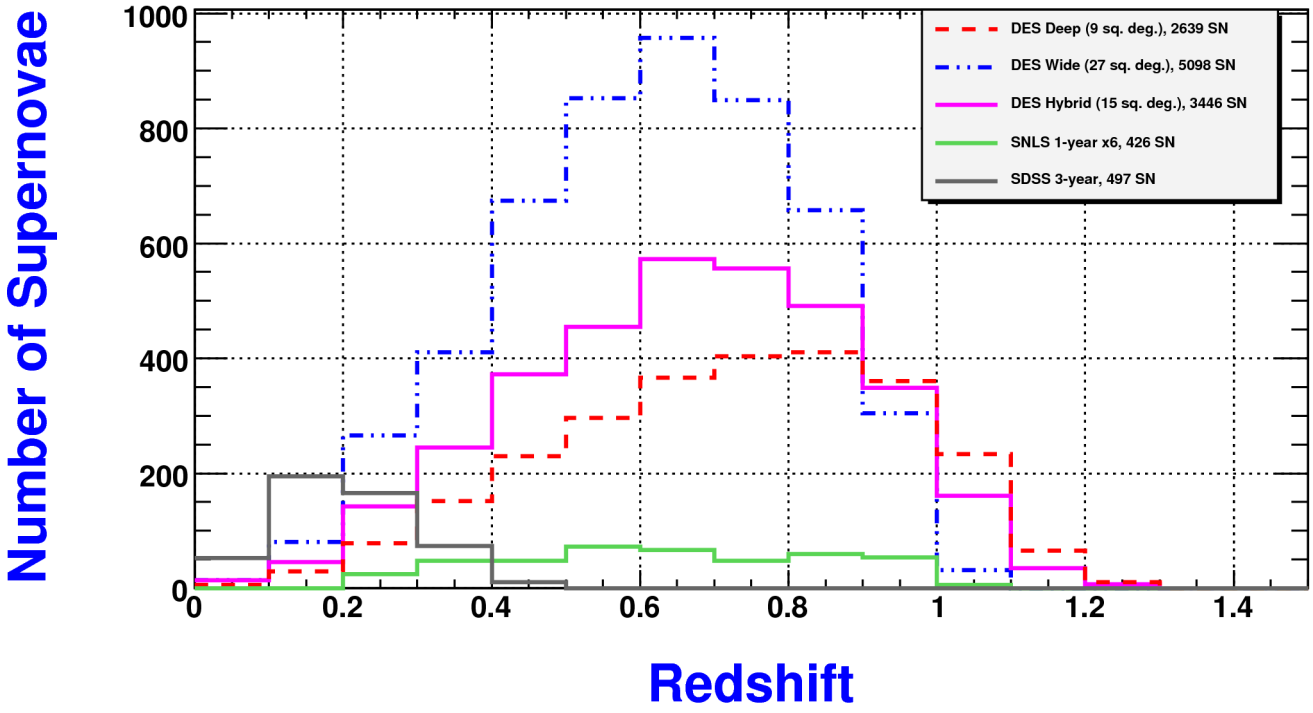




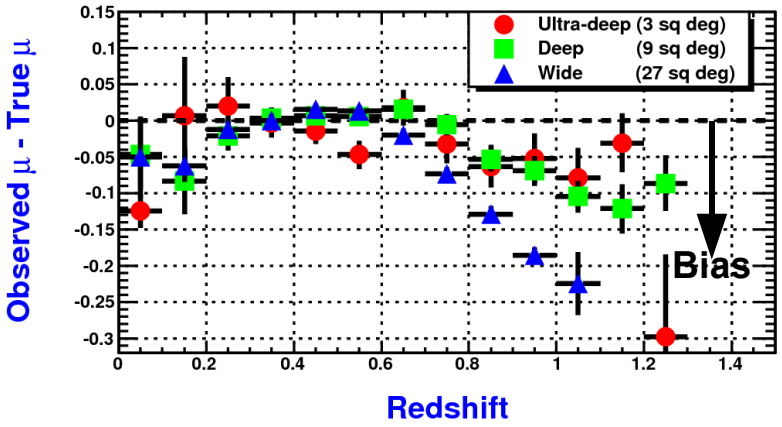
Error on the Hubble diagram for ultra-deep, deep, & wide surveys (3, 9, 27 sq. deg., respectively)

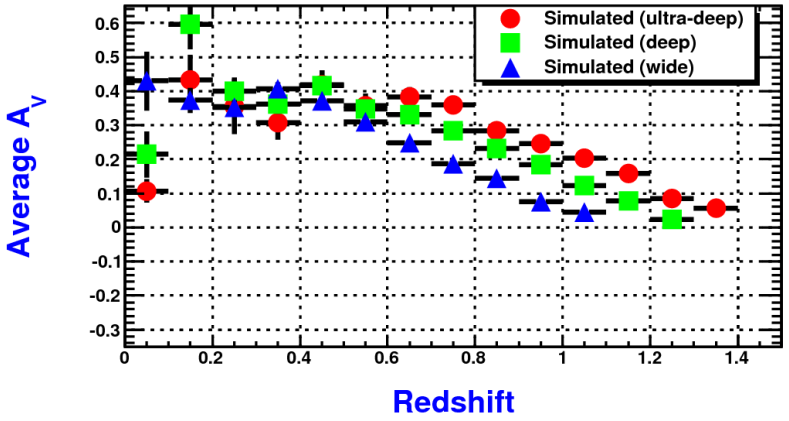


Comparison To Current Surveys



Sensitivity Of μ To Selection Efficiency



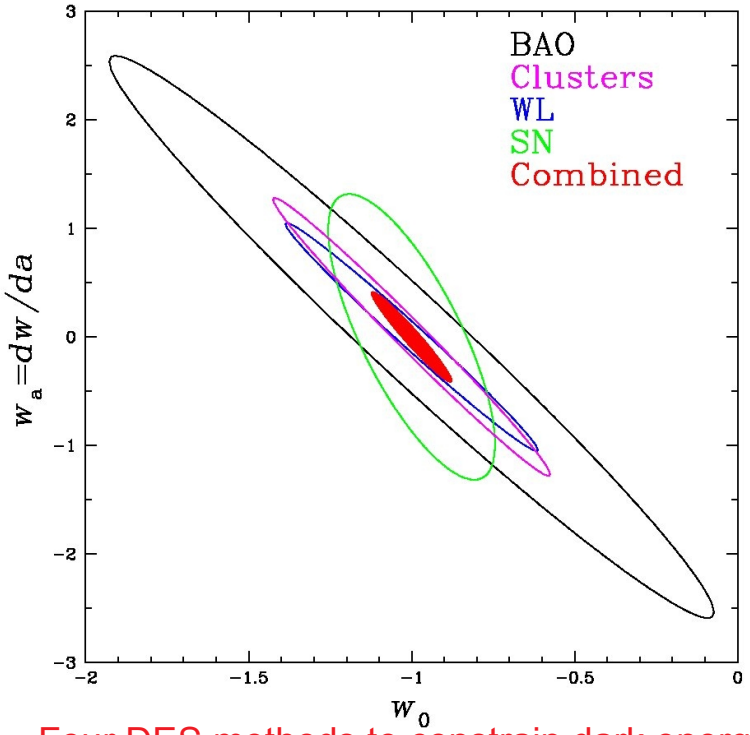


A bias in μ is evident in the difference in the fitted and simulated values, arises from selection efficiencies not being taken into account, and illustrates the magnitude of the μ-correction that will be needed

Survey Figure Of Merit (FoM)

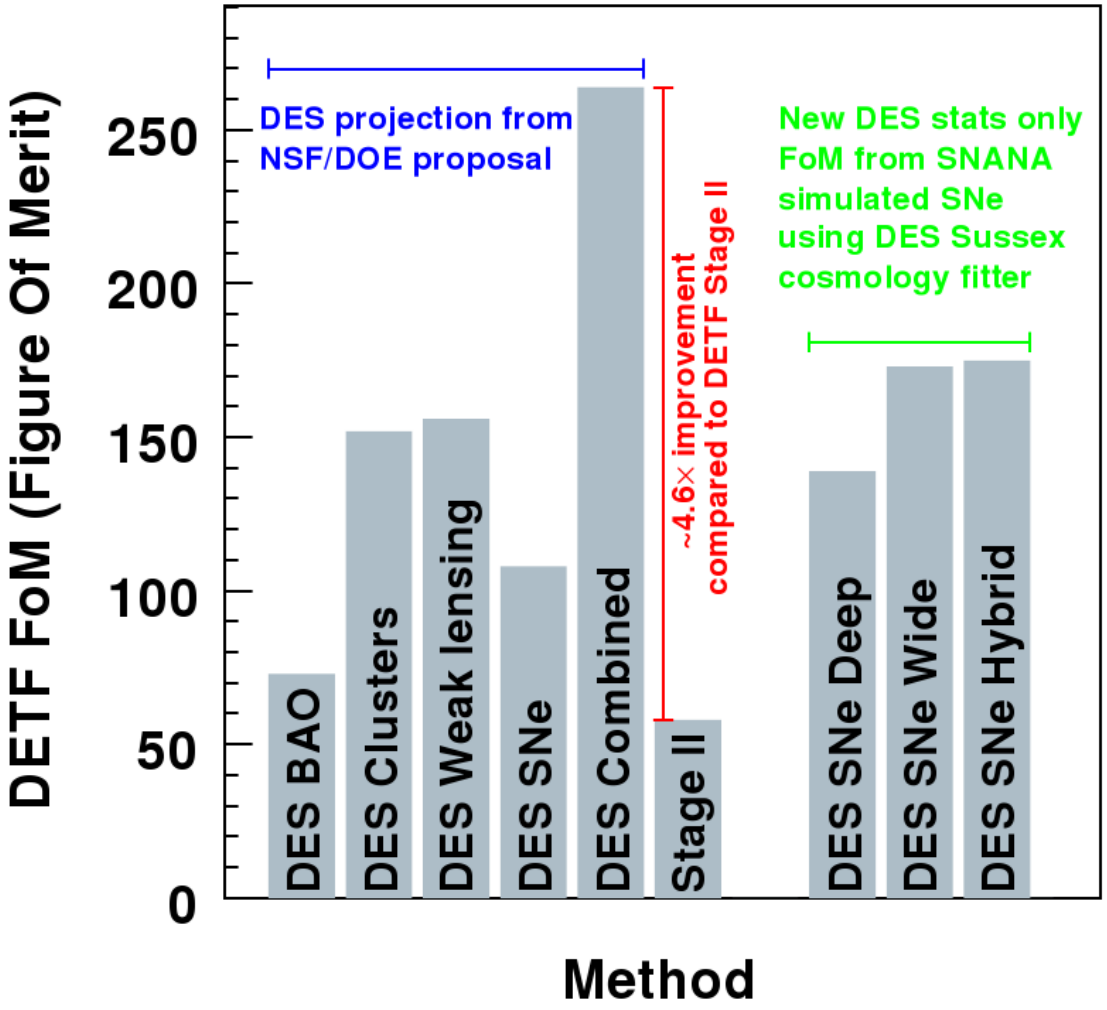
DARK ENERGY SURVEY

- Dark Energy Task Force (DETF) FoM: inverse size of $w_a - w_o$ error ellipse
  - $w(a) = w_o + (1-a)w_a$
  - a = scale factor
  - w_o = w at present epoch
  - w_a = rate of change of w with a
- Inverse area means bigger is better



Four DES methods to constrain dark energy (plot from NSF/DOE proposal including Planck priors but NOT the DETF Stage II constraints)

Dark Energy Task Force (DETF) FoM For DES



DES Systematics

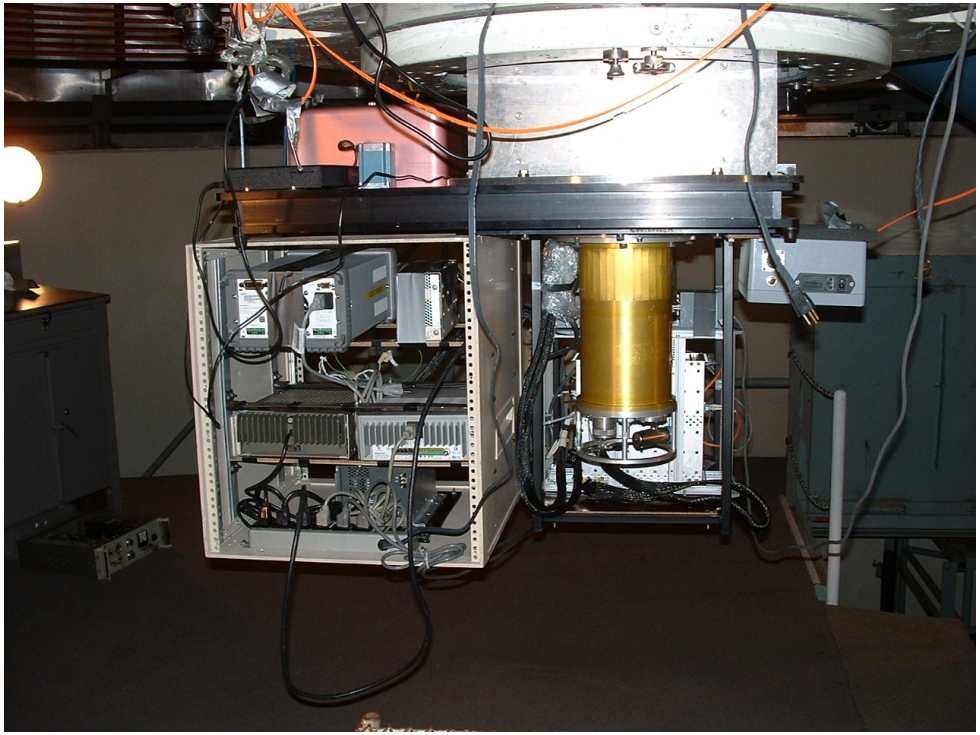
DARK ENERGY SURVEY

- Systematics errors becoming dominant factor for SN cosmology
- Systematic effects to consider:
  - light curve model
  - dust extinction vs. intrinsic color
  - photometric calibration
  - non-1a background
- DES SN survey strategy: best FoM + control of above systematics
- DES SN working group shifting focus to systematics study

Test DES

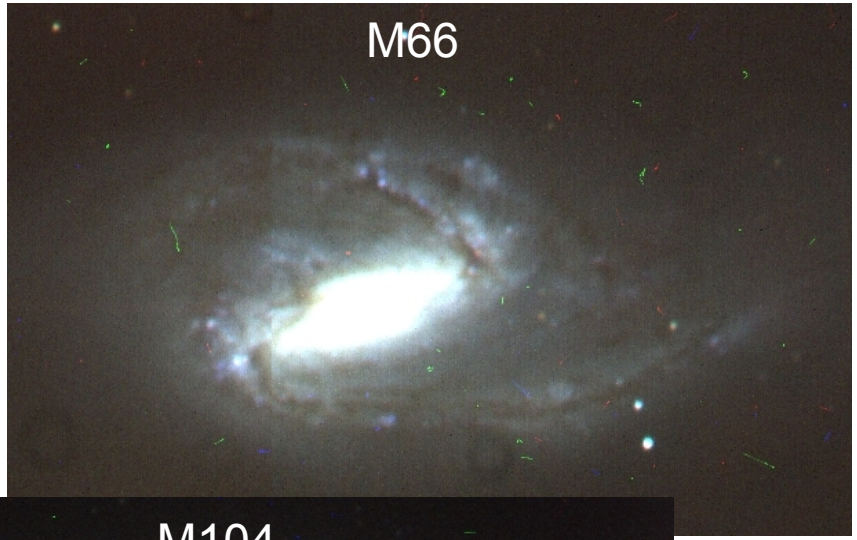
DARK ENERGY SURVEY

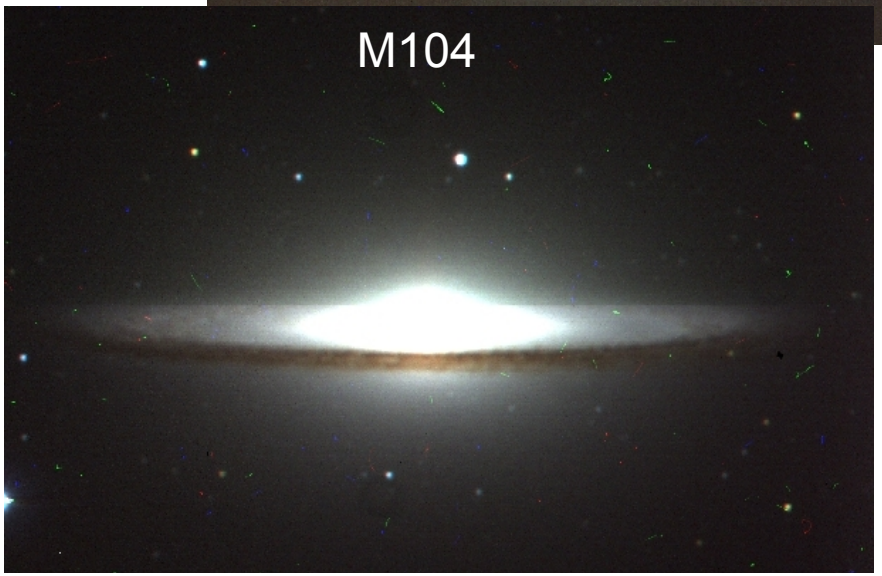
Recent test on 1m telescope at CTIO (1 week test with 1 CCD)



DES Test Images

DARK ENERGY SURVEY





100-sec raw images taken with single 2Kx2K DES CCD on 1m telescope

Summary & Conclusions

DARK ENERGY SURVEY

- DES will offer substantial improvement in SN cosmology
- DES simulates SN light curves via realistic SNANA package
- Light curves harnessed to study effects of:
  - survey depth (ultra-deep vs. deep vs. wide)
  - choice of filter sets & exposure times
  - cadence including weather
  - magnitude of a selection bias
  - color systematics including fitting A_v/R_v instead of fixing R_v
- FoM simulation $\Rightarrow$ constraint on optimal survey strategy
- Ultimately: peer reviewed DES SN strategy paper
- DES on schedule for first light in 2011

Thank you for your attention!

The Blanco telescope dome at Cerro Tololo, Chile. Single, non-composite image taken using a 2Kx2K scientific CCD temporarily mated to a custom camera. 20 sec exposure, 40mm f/4 lens, starlight only.
Credit: Roger Smith/NOAO/AURA/NSF